WASHINGTON COASTAL KELP RESOURCES
Port Townsend to the Columbia River
Summer 1994

Introduction

Along the Washington coast, there is an abundant "kelp" resource assemblage present (brown seaweeds - Order Laminariales), representing three families, 16 genera and 26 species, more than any other area worldwide (Druehl 1969). Of these, the dominant, near shore, surface canopy forming species include *Nereocystis luetkeana* (bull kelp) and *Macrocystis integrifolia* (giant kelp). These species are present along 313 kilometers (12%) of the coast of Puget Sound and the Strait of Juan de Fuca (Thom and Hallum 1990), and along the outer coast from Cape Flattery to Destruction Island.

Each surface canopy, supported by air-filled pneumatocysts, is composed of individual plants that are attached to the bottom sub-tidal habitat by root-like "holdfasts." The vertical stipes, stretching from the sea floor to the surface canopy, provide critical habitat for numerous species of commercial and sport fish, as well as invertebrates (summary: Strickland and Chasan 1989). Along the central California coast, 77 species of fish have been identified in kelp forests (Miller and Geibel 1973), and McLean (1962) identified 204 species of invertebrates in a predominately *Nereocystis luetkeana* kelp forest located south of Monterey. Prominent marine mammals, such as seals and sea lions, are also associated with this important near-shore habitat (Morejohn 1977), and most recently, sea otters have become re-established within the kelp beds of the Washington outer coast (Bowlby *et al.* 1988).

Nereocystis luetkeana occurs from Point Conception to the Eastern Aleutian Islands (Druehl 1970), and is the dominant, surface canopy kelp north of Santa Cruz, California. Its hydrodynamic shape makes it especially well suited to high exposure, "open coast" environments (Foster and Schiel 1985). *Nereocystis* is predominately an annual (Abbot and Hollenberg 1976), although mature plants have been seen to persist for up to 18 months. Impressive growth rates of up to 10 cm per day have been observed in young plants, and the mature surface canopy reaches its maximum extent in July through October. Sporangial sori mature at the surface between May and December, drop from the blade, and sink to the sea floor before releasing their spores (Abbot and Hollenberg 1976).

Macrocystis integrifolia has a range similar to bull kelp (Druehl 1970), and may form thick canopies in shallow water that is protected from heavy wave action. *Macrocystis* is a perennial, at least the basal holdfast and attached sporangial thalli. It develops its maximum surface canopy between May and October, and is found on gently sloping protected rocky habitat from the intertidal to shallow subtidal (Abbot and Hollenberg 1976).

Mixed canopies, containing both *Nereocystis* and *Macrocystis,* are present along much of the Washington state coast-line west of Low Point, and when these species co-occur, *Nereocystis* is most commonly found offshore and *Macrocystis* inshore (Rigg 1915).

The areal extent of the total kelp canopy occupied by each of these individual species is dynamic from year to year. Annual fluctuations in canopy species composition are thought to be the result of a complex combination of physical, chemical, and biological factors (Foster and Schiel 1985). Water motion (Rosenthal et al. 1974), water temperature/nutrients (Craig Barilotti pers. comm.), light intensity (Luning 1981), available habitat, and invertebrate predation (Foster and Schiel 1985) have all been associated with kelp canopy health and development. The relationships of these individual factors, and identification of those that may be "limiting" at any one given time, have yet to be fully understood, and continue to be the subject of numerous ongoing research investigations. In addition, adjacent kelp forests that appear to be exposed to similar physical factors may frequently produce vastly different canopy species compositions, further revealing the complexity of this dynamic habitat.

The effects of an ever increasing sea otter population on the state-wide kelp resource, and a better understanding of the role of the otter in structuring near-shore ecology, are the subject of ongoing research interest (Kivitek 1989). Their predation on invertebrate kelp grazers, mainly sea urchins (Jameson 1986), has been shown to dramatically reduce the density of these species, and to increase the kelp canopy areal extent in areas of significant otter abundance (Kivitek 1989). This increase in kelp canopy extent has been observed to have dramatic effects on the diversity and abundance of associated species, and the resulting near-shore community structure (Estes and Palmisano 1974). Additional research will be needed to document the long-term effects of this important marine mammal on the Washington coastal kelp forest ecosystem.

In addition to the natural effects of physical, chemical, and biological factors on the nearshore environment, occasional “man-caused” pollution events may have significant additional effects on species abundance and diversity (Foster and Schiel 1985). On July 22, 1991, the fish processing ship “Tenyo Maru” collided with the Japanese freighter “Tuo Hai” approximately 22 miles WNW of Cape Flattery (Craig Petersen pers. comm.). The Tenyo Maru was heavily damaged from the collision, and sank in over 500 feet of water. Within minutes, an estimated 100,000 gallons of #2 diesel fuel, and an unspecified quantity of IFO #180 was released into the marine environment. The prevailing WNW winds and seas carried the fuel oil towards both Vancouver Island and the Cape Flattery area. During its time at sea the oil was weathered, and would eventually be observed as "tar balls" in both the kelp beds, and to a lesser extent on rocks and beaches from Neah Bay to Cape Alava. Ongoing clean-up operations continued for several months after the spill in an attempt to minimize damage to the marine environment. Questions were raised from this event, regarding the long-term effects of petroleum pollution on these kelp canopy forming species.

Macrocystis canopies have been observed to be largely un-affected by hydrocarbon pollution, presumably due to the temporary protection provided by plant produced mucus (Mitchell *et al.* 1970), and the physical location of the reproductive sporophylls near the basal holdfast. Pollution effects on *Nereocystis* canopies have only been recently investigated (Antrim *et al.* 1995). Surface stipe tissue bleaching and loss, as a result of hydrocarbon contact, was observed both by Antrim (1995), and during the field clean-up operation following the "Tenyo Maru" spill. However, it is still unclear whether or not subsequent seasonal *Nereocystis* recruitment is affected by these polluting elements.

The dynamic and sometimes vulnerable nature of the coastal kelp resource, considering its importance as habitat and food for hundreds of related species, points out the need for systematic methods of accurately assessing its areal extent and vitality. Until 1989, the Washington coastal kelp resource had only been sporadically mapped and analyzed since an initial state-wide visual survey conducted in 1912-1915 (Rigg 1912, 1915 - see: Mumford (1989) for review of previous survey efforts). Earlier ground based estimates of kelp canopy areal extent have given way to modern aerial surveys, which provide a cost effective and accurate methodology for the mapping and quantification of near-shore kelp resources (Jamison 1971).

A substantial portion of this dynamic kelp resource habitat falls within the newly established (July 16, 1994) Olympic Coast National Marine Sanctuary (OCNMS). The management area occupies 3300 square miles, and includes the coastal zone between Neah Bay and the Copalis River (NOAA 1995). Within this sanctuary are three national wildlife refuges: 1) Flattery Rocks, 2) Quillayute Needles, and 3) Copalis. OCNMS administration has four major components and mandates: 1) sanctuary management, 2) public education, 3) environmental regulation, and 4) an ongoing research program.

The Washington Department of Natural Resources (WDNR) manages two million acres of state-owned aquatic lands (Mumford 1992). Aquatic or submerged lands include tidally influenced lands such as tidelands and bedlands, as well as the beds and shores of navigable freshwater bodies. Within these areas are located: 1) all subtidal aquatic plant communities (kelp, seagrass, and seaweeds), 2) over 40% of intertidal plant communities (seaweeds and seagrasses), and 3) freshwater plants living on the beds and shorelands of 70% of the navigable rivers and lakes. Washington State's aquatic lands have been a significant public resource since the were granted form the federal government at statehood in 1889. These lands are managed for the benefit of all current and future citizens of the state. Certain public aquatic rights are maintained in trust for the people, including the public rights of fishing, navigation and commerce. These rights are public ownership interests that apply to all tidelands, shorelands, navigable waters and underlying bedlands.

An Aquatic Management Plan was adopted by the WDNR in 1987. It calls for aquatic plant management through preservation, habitat protection and restoration, harvest management and cultivation. In 1988, WDNR imposed a moratorium on the commercial harvest of all wild seaweeds until such time as more specific management guidelines can be adopted. Experimental harvest of seaweeds is currently permitted if information is generated that will further management objectives.

In response to this conservation and management mandate, Ecoscan Resource Data was first contracted in 1989 by WDNR to establish a kelp resource mapping and analysis program along the coastal zone between Port Townsend and the Columbia River. Similar annual inventories were repeated in 1990, 1991 and 1992, and subsequently in 1995 and 1996 (Van Wagenen 1989 - 1992, 1995, 1996a). Results from the first four inventories were summarized following the 1992 survey (Van Wagenen 1989 - 1992b).

The primary objective of this inventory, as initiated in 1989, was the establishment and maintenance of an annual, state-wide, coastal kelp resource mapping and monitoring program that would accurately reflect the seasonal maximum resource areal extent, by species. The methodology utilized was designed to not only allow a systematic, accurate analysis of multi-year data from current and future inventories, but to also allow meaningful comparisons with historic surveys as well.

Measurements of resource abundance were tabulated and presented at three levels to serve the needs of: a) field researchers conducting small-scale investigations within individual kelp beds, b) administrative resource managers considering long-term trends over large areas, and c) agency computer GIS professionals, utilizing kelp canopy measurements as another "layer" in a larger environmental data model.

Methods and Results

The methodology utilized in this kelp resource inventory was divided into four phases: 1) Kelp canopy aerial photography and species composition estimations, 2) Qualitative kelp canopy mapping and species determination, 3) Quantitative kelp canopy and planimeter area and density analysis, and 4) Geographic Information System (GIS) data-layer creation and file transfer. Methods utilized on this current survey were similar to those used in previous inventories (1989-1992) to ensure data compatibility and comparability with these and other earlier studies.

Although the defined scope of this study was limited to measurement of current resource abundance, specific comparisons will be made with the last previous systematic analysis (1992) to document short-term changes in kelp canopy extent.

1) Kelp Canopy Aerial Photography and Species Composition Estimations

A) Kelp Canopy Aerial Photography

The methodology related to obtaining high-quality imagery of the fully developed 1994 Washington coastal kelp resource was divided into two sections: 1) survey timing, imaging, and logistic considerations, and 2) photography of the 1994 kelp resource.

1) Survey Timing, Imaging, and Logistic Considerations

The seasonal timing, photographic scale, and flight parameters of this aerial survey were established, as in previous surveys, to systematically obtain imagery that best represented the maximum areal extent of the current kelp resource. Acceptable "survey windows" were chosen for the aerial overflights in response to several biological (seasonal timing of maximum canopy development), physical (tidal level, weather and sea state), and logistic factors (length of survey range).

Seasonal timing of maximum kelp canopy development was the major biological factor involved in scheduling this resource survey, and established the criteria around which all other logistic decisions were made. It has been generally accepted, in Washington state, that the maximum extent of canopy forming kelp species occurs in August through October, with maturity of the *Nereocystis* canopy determining the beginning of this "biological window", and late summer storms determining the end (Thomas Mumford, Ron Jameson pers. comm.).

Within this three month period, several acceptable "tidal windows" were selected (utilizing NOAA tide tables for Aberdeen and Port Townsend) that would allow the aerial imagery to be obtained at tidal levels of less than +1.0' MLLW. Once the tidal windows were established, the actual survey was conducted during the first window that had acceptable associated environmental conditions. These conditions included adequate ceiling and visibility (>8,000' MSL and five miles), surface winds less than ten knots, sea/swell less than five feet, and a sun angle of greater than 30 degrees from vertical. In Washington state, changeable weather (especially coastal fog, high winds and sea state) can be a major limiting factor on survey timing, and can frequently reduce the number of acceptable survey days in a given season to less than five. During the previous four surveys, virtually all of the aerial imagery was obtained within these optimum biological, tidal, and environmental windows, thereby allowing meaningful comparisons of seasonal kelp resource areal extent.

The aircraft altitude (7,500' MSL) and photographic scale (1"=2,500') used for these surveys was selected to provide a good balance between resource resolution and rendition on the imagery, the selected base-mapping scale (1:12,000), and the overall length of the survey area (110 miles). At this altitude and photographic scale, the entire survey range containing kelp (Port Townsend to Destruction Island) can be accurately recorded during a single low-tidal period. Considering the changeable nature of Washington coastal weather; this methodology has allowed the maximum utilization of the few optimum survey dates. With regards to resource resolution on the imagery; ground truth measurements have indicated that the smallest kelp "dots" on the 1:12,000 scale maps (approximately the size of a text "period" from this document), represent as few as three surface stipes from a single *Macrocystis* kelp plant.

The film used on this survey was 70 mm Kodak color infrared - type 2443, the accepted standard for use in documenting the areal extent of marine surface vegetation. Its ability to increase the contrast between kelp and the surrounding water, without sacrificing resolution, makes it ideal for resource surveys of this type. Despite this ability, infrared film does have limitations regarding its utility in recording sub-surface coastal kelp canopies. Due to its poor water penetration properties of approximately two feet (Helgeson 1970); this film will not record kelp stipes that are significantly pulled below the surface, due to high winds and seas, high tides, and tidal currents. This especially affects sparse *Nereocystis* canopies, which can be completely submerged by the above factors (especially tidal currents), and not recorded on the imagery. Careful attention to survey timing that corresponds with acceptable winds, seas, and the "time of the low tide" at each coastal location, is necessary to insure proper canopy rendition.

2) Photography of the 1994 Kelp Resource

When the biological, tidal, environmental, imaging, and logistic factors were considered together, three possible "optimum survey windows" were created for the 1994 kelp resource inventory: 1) August 21-23, 2) September 5-7, and 3) September 17-18. Aerial photography operations conducted during each of these windows would yield imagery that best represented the maximum resource areal extent.

Aerial photography of the 1994 kelp resource was accomplished on September 17, during the third survey window. Aircraft mechanical problems prevented the utilization of the first two survey periods, and fortunately, good-excellent environmental conditions were encountered during the third window (figure 1.1). Continuous, sequential, vertical photographs (20%-30% overlap) were taken of the coastal zone between Port Townsend and Destruction Island, and all kelp canopies within this survey range were recorded on the imagery. Approximately 20% shoreline was included on each image to facilitate accurate projection onto the base-line maps. Larger canopies, that were not fully recorded on the initial "in-shore" photographic transect, were referenced on parallel "off-shore" flight lines. Each new transect was "side-lapped" by 30%-40% with those on-shore, to facilitate the accurate mapping of these off-shore canopies.

The imagery from survey was judged of good-excellent quality, and with minor exception, allowed the complete mapping and analysis of the state-wide kelp resource. Imagery limitations affecting the accuracy of the current survey are presented in the discussion section. The imagery is presented as: "Washington Coastal Kelp Resources - Summer 1994 - Aerial Survey Imagery" (Binder 1/1 - "Port Townsend to Destruction Island").

B) Kelp Canopy Aerial Species Composition Estimations

In order to facilitate the accurate determination of canopy species composition during the mapping process, low-altitude observation ("air-truth") flights were conducted from 500' - 1,000' MSL on September 17-18, 1994. A total of six flight hours were spent making independent qualitative observations of individual kelp canopy species composition. All surface canopies within the survey range were observed on both survey dates, and visual observations of species areal extent were recorded on maps from the 1992 survey.

Visual observations of species composition were spatially divided into three "species classes", which included: 1) 100% *Nereocystis luetkeana*, 2) 100% *Macrocystis integrifolia*, and 3) "mixed canopies", containing both species. The composition of each mixed canopy area was also estimated (% *Nereocystis* / % *Macrocystis*), based on the relative sea surface area occupied by each. Results of these mixed canopy estimations were tallied in multiples of 10 percent (80% "*Nereo*" / 20% "*Macro*", etc.), to allow faster, more consistent data acquisition from the aerial platform. These "air-truth" observations were utilized in conjunction with the imagery to determine the areal extent of each species, as described under "Kelp Canopy Species Determination and Planimeter Area Mapping." Associated environmental data and observations from each of the visual overflights are presented in figures 2.1 - 2.2.

2) Qualitative Kelp Canopy Mapping and Species Determination

Kelp canopy mapping was accomplished in three phases: A) Base-line map preparation, B) Kelp bed canopy area mapping and indexing, and, C) Kelp canopy species determination and planimeter area mapping.

A) Base-line Map Preparation

The base-line maps for this coastal kelp survey were originally designed for the 1989 inventory, and subsequently used again in the 1990, 1991 and 1992 efforts. This base-map series represents an accurate and continuous depiction of the Washington state coastal zone from Port Townsend to the Columbia River, and allowed the systematic mapping of the range-wide resource.

Forty-one contiguous base-line maps (24"x36", scale 1:12,000) were made of the Washington coastal zone, using USGS 7 1/2' quadrangle maps (scale 1:24,000) as a reference. These maps offered extensive shoreline detail, high accuracy, and continuous coverage for the entire survey range. Each of the "quad" maps was enlarged to a scale of 1:12,000 on a calibrated photocopier (Sharp "8400"). The contiguous "shoreline" portions of each of the enlarged maps were then assembled together, and became the land reference on each of the base maps. All standard detail from these USGS maps was preserved, including: prominent shoreline features, offshore rocks, rivers, beaches, rocky intertidal habitat, towns, harbors, and topographic relief.

A range-wide index was included, showing the location of each individual map plate (figure 3.1). In addition, the maps were indexed by map number (table 1), and map name (table 2). Numbered kelp beds present on each map page were also included in these indexes.

To aid in orientation and facilitate "field use" of the maps, prominent geographic features were listed alphabetically in tabular form (table 3), with cross-references to the map name and number where they were found.

Four control points (A-D), oriented to the Universal Transverse Mercator (UTM) coordinate system - Zone 10, were chosen for each map that contained kelp, and were listed in table 4. This coordinate system was chosen, since a UTM 1000 meter "grid" was already on the majority of the USGS 7.5' "quad maps". After enlargement, this grid was preserved, and allowed the accurate establishment of these references. The points are arranged (A-D) using east to west orientation on maps W1-W16, and, north to south orientation on maps W17-W25. Maps W26-W41 do not contain control points, since kelp canopies have not been observed within this range.

B) Kelp Bed Canopy Area Mapping and Indexing

All color infrared slides from the survey were projected onto the base-line maps, and after aligning common shoreline features from each media, individual kelp plants and kelp canopies (see glossary) were hand transferred. The transfer process specifically involved: 1) the visual analysis of the areal extent of kelp represented on each slide by reference to color and surface appearance, 2) the identification of the "usable" portion of the image that was largely distortion-free (center three-fourths), 3) positioning this "usable" portion of the projected image in its proper location on the base-map, with regard to both shore-line features and kelp from other overlapping imagery, and 4) the black-shading of all visible kelp, both developed canopies and individual plants. These black-shaded areas represented the areal extent of the actual kelp plants composing the surface canopy, and areas within the perimeter of the canopy that did not contain kelp were left un-shaded. When fully rendered from the survey imagery, each mapped canopy closely resembled the appearance of the actual surface canopy, when viewed from above. Kelp bed index numbers (see glossary) were then assigned as in the previous surveys, allowing a more specific and detailed subsequent area analysis.

These mapped canopies represented the qualitative kelp canopy area (see glossary) occupied within the survey range, and are presented in Section 4 - "Kelp Bed Canopy Area Maps: 1-41" (24"x36", 11"x17", and 8.5"x11").

A set of equivalent maps covering the range from Port Townsend to Destruction Island were made on "mylar" (24"x36") for qualitative "overlay" comparisons with previous surveys. They are presented as: Section 4 - "Mylar Kelp Canopy Area Maps: 1 - 25".

C) Kelp Canopy Species Determination and Planimeter Area Mapping

Kelp canopy species composition was determined by combining both visual observations from the two low-altitude over-flights and quantitative data from the vertical imagery. The aerial observations of canopy species composition corresponded well with that determined photographically. This allowed the accurate distinction of each of the three species classes (100% *Nereocystis*, 100% *Macrocystis*, and "mixed" canopy areas). On the imagery, *Nereocystis* and *Macrocystis* areas were separated visually by both canopy color and surface appearance. *Macrocystis* appeared reddish-brown, and had a consistent surface canopy presence on the imagery, with few color and density irregularities.

Nereocystis appeared reddish-orange, and was much more irregular in appearance, with numerous "dense" and "sparse" areas within close proximity. The dense areas formed bright red-orange patches, and were clearly identifiable both in "100 % *Nereocystis*" and mixed canopy areas. The areal extent of each species class was spatially indicated on the canopy area maps (section 4), by encircling each class location with a perimeter polygon.

Once the mixed canopy areas were identified, with the help of the aerial observations, the imagery was projected for analysis onto a random dot grid. Within each mixed canopy polygon, all dots were tallied as to whether they fell in a *Nereocystis* or *Macrocystis* area. These data were compared with total number of dots within the mixed canopy area as a whole to obtain percent canopy species composition. Results were rounded to the nearest 10% multiple for each species, as in the aerial estimations. These quantitative results compared very closely to those obtained from the low-altitude over-flights, and were used in the subsequent area analysis to determine *Macrocystis* and *Nereocystis* areal extent (ha) in these "mixed" canopy areas. The aerial visual observations were not used in the quantitative analysis of species composition, unless a positive identification of the species, where the random dots were located, was not obtainable from the imagery. In these cases, which occurred less than ten percent of the time, aerial observations of species composition were used.

Planimeter area maps were created by establishing a computer derived perimeter polygon around the kelp within each species class, corresponding to the <u>qualitative planimeter area</u> occupied by each (see glossary).

These <u>qualitative kelp canopy species and planimeter areal extent data</u> are presented in <u>Section 5</u> - "Kelp Canopy Planimeter Area/Species Composition Maps: 1 - 25. On the 24"x36" color maps, the three classes were noted as: 1) 100% *Nereocystis* - "red", 2) 100% *Macrocystis* - "blue", and 3) mixed canopy areas - "green." On the 8.5"x11" and 11"x17" maps the three species classes were noted as: 1) 100% *Nereocystis* - "N", 2) 100% *Macrocystis* - "M", and 3) mixed canopy areas - "B" (both species).

3) Quantitative Kelp Canopy/Planimeter Areas and Relative Density Analysis

The quantitative analysis of range-wide kelp resource abundance was divided into two sections: a) analysis of the 1994 Washington kelp resource, and b) comparisons of current resource areal extent with that present in 1992. Within each section data was tabulated and plotted at three levels, to better depict both the "small and large scale" dynamics of kelp canopy abundance. These three levels included analysis by: a) kelp bed number (level 1), map number (level 2), and survey range (level 3). Specific findings and observed trends in resource abundance, for each analysis level, are presented in the "Data Summary" section.

A) Analysis of the 1994 Washington Coastal Kelp Resource

Quantitative kelp canopy and planimeter areas (see glossary) were accurately determined from the maps using computer image processing techniques. Each map page was digitized, using a Microtek MS-300Z flat-bed image scanner. Each index was determined by screen "pixel counting", utilizing "Global Lab Image" (V3.1) image processing software (Data Translation). Kelp canopy areas and planimeter areas were tabulated by kelp bed number, and divided into each of the assigned species classes. Mixed canopy/planimeter area data, for each species, were determined by multiplying the total mixed canopy "pixel count" by the calculated percent composition of each.

Level 1 - Analysis of the 1994 kelp resource extent, by kelp bed number

Quantitative kelp bed canopy area data, by kelp bed number and species class, are presented in table 5. An area summary of each kelp canopy, by species, is also included, in addition to an estimate of mixed canopy and total canopy percent species composition. These canopy area and species composition data, by kelp bed number and species class, are plotted in figures 5.1 (5.1.1 - 5.1.4).

Quantitative kelp bed planimeter area data are presented in similar form to the kelp canopy area data in table 6, and plotted in figures 6 (6.1.1 - 6.1.4).

Kelp canopy and planimeter area data are summarized in table 7, in addition to the calculation of a Relative Density Index value (RDI - see glossary) for each species, and for the total kelp canopy. Kelp canopy area, planimeter area, and RDI data are plotted in figures 7 (7.1.1 - 7.1.4).

Level 2 - Analysis of the 1994 kelp resource extent, by map page number

Measurements of kelp canopy/planimeter area and RDI were also tabulated by map page and species (table 8), to better understand the overall distribution and density of the Washington coastal kelp resource. Kelp canopy area and species composition, by map page, are plotted in figure 8.1.1, and similar indices utilizing planimeter area measurements are plotted in figure 8.2.1. A final summary of canopy/planimeter area and RDI are plotted, by map page, in figure 8.3.1.

Kelp canopy range-wide species distribution, expressed as "percent of individual species" and "percent of the total kelp resource area" contained on each map page, is presented in table 9. For example, on map page 16 (Cape Flattery area): 16.9% of the total *Nereocystis*, 7.4% of the total *Macrocystis*, and 10.7% of the total kelp resource canopy area is found.

These data are plotted, both for individual species and for the entire resource, in figure 9.1.1, (canopy area), and figure 9.2.1 (planimeter area).

Level 3 - Analysis of the 1994 kelp resource extent, by <u>survey range</u>

In addition to measurements tabulated by kelp bed number and map page, summaries of areal extent indices were provided for three large survey ranges, and four additional special areas of interest. This allowed a better understanding of the overall distribution and dynamics of the current kelp resource, in addition to comparisons with other previous inventories. These larger ranges included: 1) the "Straits of Juan de Fuca" - Port Townsend to Cape Flattery (canopies 1.1-16.2), 2) the "open coast- Cape Flattery to the Columbia River" (canopies 16.3-41.1) , and 3) the "total kelp resource" - Port Townsend to the Columbia River (canopies 1.1-41.1).

Several special areas of research interest were also selected. The total kelp from Port Townsend to Disque (canopies 1.1-9.3) and from Twin Rivers to Cape Flattery (canopies 10.1-16.2) was tabulated, to allow comparisons with selected historic surveys that included this measurement. In addition, resource extent within the OCNMS (Neah Bay to the Copalis River - canopies 15.3-31.1), by species, was tabulated to establish a base-line abundance within this region. Finally, the range from Neah Bay to Cape Alava (canopies 15.3-19.2), in addition to the area outside this range (canopies 1.1-15.2 and 20.1-41.1) was included, in reference to the area affected by the 1991 "Tenyo Maru" oil spill.

<u>Kelp canopy/planimeter area and RDI</u> data, for each of these survey ranges, is presented in <u>table 10</u>. As in table 9, calculations for "percent of individual species" and "percent of the total kelp resource" are included. These data are plotted, by survey range, in <u>figure 10.1.1</u> and "special ranges of interest" in figure <u>10.2.1</u>.

B) <u>Comparisons of the 1992 and 1994 Washington Coastal Kelp Resource</u>

Changes in kelp resource areal extent observed since the last systematic survey (1992) were included for comparative purposes, at all three analysis levels. Care must be taken in interpreting these observed changes, since only two data sets are involved spanning two years. At best, these data represent short-term changes only and may or may not reflect long-term trends in kelp resource extent and distribution.

Level 1 - 1992 and 1994 kelp resource extent comparisons, by <u>kelp bed number</u>

<u>Canopy area</u> measurements from the 1992 and 1994 surveys, in addition to resource percent change by kelp bed number and species, are included in <u>table 11</u>.

<u>Planimeter area</u> measurements of these indices presented in <u>table 12</u>. These data are plotted in <u>figures 11 and 12</u> (11.1.1-11.1.4 and 12.1.1-12.1.4), respectively.

Level 2 - 1992 and 1994 kelp resource extent comparisons, by <u>map page number</u>

<u>Canopy/planimeter area/RDI and percent change</u> in these indices for each of the surveys, by map page, is included in <u>Table 13</u>, and plotted in <u>figures 13.1.1 and 13.2.1</u>.

Level 3 - 1992 and 1994 kelp resource extent comparisons, by kelp survey range

Canopy/planimeter area/RDI data from the 1992 and 1994 surveys, in addition to resource percent change by survey range, are included in table 14, and plotted in figures 14.1.1 and 14.2.1.

In order to evaluate the significance of observed changes in resource extent between the two surveys, a t-test ("paired two sample for means") was applied to the data sets from tables 11 and 12. This test evaluates whether a samples' means are distinct, and does not assume equal population variance (Sokal and Rohlf, 1981). This test was judged appropriate, since there was a natural pairing of measurements making up each distinct and summarized value for canopy/planimeter area and RDI. Each data pair were analyzed at the 95% confidence level (p = .05), and the results of the tests are summarized in table 14, and plotted figures 14 (14.1.1 and 14.2.1).

4) Geographic Information System (GIS) Data-layer Creation and file transfer

Kelp canopy elements from each of the original "Kelp Bed Planimeter Area Maps" were digitized (all counter-clockwise) on a 24"x36" Calcomp 23360 tablet digitizer into an ERDAS - "IMG" file (see glossary). All map files were rectified to the UTM Coordinate System - Zone 10, utilizing the Clark 1866 Spheroid and Datum . Five GIS "class values/colors" (see glossary) were established for each map file, representing: 1) "Map Corners" (symbol-white) - GIS value "0", 2) Control Points (polyline-purple) - GIS value "1", 3) 100% *Nereocystis* canopies (polygon-red) - GIS value "2", 3) "Mixed" canopies (polygon-green) - GIS value "3", and, 4) 100% *Macrocystis* canopies (polygon-blue) - GIS value "4". The control points in each map file were arranged (A-D) from east to west on maps W-1 to W-16, and north to south on maps W-17 to W-25, as previously discussed.

All digitized elements were grouped by class value, and files were named according to the convention: 1) project title - "Washington Coastal Kelp Resources" (WCKR), 2) survey year (94), and 3) map number (01-25) - example "WCKR9410.IMG." Map data files are included on the enclosed 3.5" HD (DOS formatted) floppy diskettes as indexed in the file table of contents (section 6).

All spreadsheet data from tables 1-14 are provided in "Excel" ("XLS" - Microsoft Inc.) file format. Each data file is included on the enclosed 3.5" HD (DOS formatted) floppy disk under the file names described in section 6.

Data Summary

The effective summary of resource extent, at three analysis levels, from 92 numbered kelp beds located on 41 map pages within 7 survey ranges, presented two challenges. The first was not "losing the forest for the trees," and the second was keeping it simple enough that investigators at each level would gain maximum utility from these data. This summary will focus mainly on a "large scale" assessment of the 1994 kelp resource, and changes observed since the 1992 inventory. As a result of this data tabulation method, though, additional "small scale" changes in kelp resource extent may become apparent, as further research is conducted. Investigators are encouraged to use these data in that regard.

Major findings from this study are presented as: 1) summary of 1994 kelp resource areal extent, by survey range, and 2) summary comparisons of the 1992-1994 coastal kelp resource.

1) Summary of the 1994 Kelp Resource Extent, by Survey Range

Kelp canopy and planimeter area data from the 1994 survey are summarized within the following ranges, and sub-ranges (table 10): a) Strait of Juan de Fuca (Port Townsend to Cape Flattery), b) open coast (Cape Flattery to the Columbia River), c) range-wide (Port Townsend to the Columbia River), d) Port Townsend to Disque and Twin Rivers to Cape Flattery, e) the Olympic Coast National Marine Sanctuary (Neah Bay to Copalis), and f) Neah Bay to Cape Alava in comparison with the remainder of the survey range. In addition range-wide kelp canopy species composition will be summarized.

A) Strait of Juan de Fuca (Port Townsend to Cape Flattery - canopies 1.1-16.2)

The total kelp canopy/planimeter area in the Straits of Juan de Fuca was 680 ha and 2,326 ha respectively, representing approximately 82% of the total kelp resource. The overall canopy density (RDI) was .29.

Nereocystis occupied areas of 267/1,196 ha (RDI=.22), representing approximately 93% of the total *Nereocystis* and 37% of the total kelp resource.

Macrocystis, within this range, occupied 413/1,129 ha (RDI=.37), representing approximately 74% of the total *Macrocystis* and 45% of the total kelp resource.

B) Open Coast (Cape Flattery to Destruction Island - canopies 16.3-41.1)

The total kelp canopy/planimeter area within the open coast range was 146/524 ha (RDI=.28), representing approximately 18% of the total kelp resource.

Nereocystis occupied areas of 11/117 ha (RDI=.09), representing approximately 7% of the total *Nereocystis* and 3% of the total kelp resource.

Macrocystis occupied an extent of 135/407 ha (RDI=.33), representing approximately 25% of the total *Macrocystis* and 15% of the total kelp resource.

As in previous surveys, no kelp was observed south of Destruction island on the open coast.

C) Total Range-wide Kelp Resource (Port Townsend to the Columbia River)

The total kelp canopy/planimeter area, on a range-wide basis, was 825/2,850 ha and the overall density (RDI) was .29.

Nereocystis occupied areas of 277/1,313 ha (RDI=.21), representing approximately 34%/46% (canopy/planimeter area values) of the total kelp resource extent.

Macrocystis areal extent was 548/1,537 ha (RDI=.36), and represented 66%/54% of the total resource.

D) Port Townsend to Disque (1.1-9.3) and Twin Rivers to Cape Flattery (10.1-16.2)

The total kelp canopy/planimeter area from Port Townsend to Disque was 199/741 ha (RDI=.27), representing approximately 25% of the total kelp resource. Similar indices within the range of Twin Rivers to Cape Flattery measured 480/1,585 ha (RDI=.30), and represented approximately 57% of the total resource.

E) Olympic Coast National Marine Sanctuary (canopies 15.3 - 31.1)

Kelp beds within the Olympic Coast NMS represented approximately 31% of the total kelp resource, with total canopy/planimeter areas of 259/882 ha (RDI=.29), respectively.

Nereocystis areal extent was 75/346 ha (RDI=.22), representing approximately 26% of the total *Nereocystis* and 11% of the total kelp resource.

Macrocystis occupied areas of 184/536 ha (RDI=.34), representing 34% of the total *Macrocystis* and 21% of the total kelp resource.

F) Neah Bay to Cape Alava in comparison with the remainder of the range

The total kelp within the Neah Bay to Cape Alava range occupied canopy/planimeter areas of 240/777 ha (RDI=.31), representing approximately 28% of the range-wide areal extent.

Nereocystis occupied 72/331 ha (RDI=.22), representing 26% of the *Nereocystis* and 10% of the total kelp resource. *Macrocystis* occupied 168/447 ha (RDI=.38), and represented 30% of the *Macrocystis* and 18% of the total kelp resource.

Kelp beds outside of this range occupied canopy/planimeter areas of 585/2,073 ha (RDI=.28), representing 72% of the total resource extent.

Nereocystis extent was 205/983 ha (RDI=.21), corresponding to 74% of the *Nereocystis* and 30% of the total resource.

Macrocystis occupied areas of 380/1,090 ha (RDI=.35), representing 70% of the *Macrocystis* and 42% of the total kelp resource

Kelp Canopy Species Composition

Kelp canopy range-wide species composition, corresponding to canopy area values (table 5), was 21%/79% *(Nereocystis/Macrocystis)* within mixed canopies, and 34%/66% within the total canopy area.

In regard to planimeter area values (table 6), canopy composition within mixed canopy areas was 27%/73% *(Nereocystis/Macrocystis),* and 46%/54% within the range-wide surface canopy.

2) Summary Comparisons of the 1992-94 Coastal Kelp Resource

Statistical comparisons (table 14) of current resource areal extent were made with that measured within comparable survey ranges in 1992, as well as numerical comparisons of canopy species composition. All significant changes were evaluated at the 95% confidence level (p=.05).

A) Straits of Juan de Fuca (Port Townsend to Cape Flattery)

The total kelp canopy area in the Straits of Juan de Fuca significantly increased from 630 to 679 ha (1992-1994), which represented an 8% gain. The total kelp planimeter area also increased 8% from 2,159 to 2,326 ha.

Nereocystis canopies experienced significant decreases in canopy/planimeter areas of 15% and 5% respectively, within this range, in addition to a significant decrease in plant density (.25 to .22). The greatest gain in *Nereocystis* extent occurred in the range of Twin Rivers to Cape Flattery, with canopies 10.5, 10.6, 11.1, 11.3, 15.2, and 15.4 experiencing increases in planimeter area of over 50%. The greatest loss of *Nereocystis* canopy occurred within the range east of Port Angeles. Numerous canopies within this range experiences losses in canopy/planimeter area in excess of 50%. Canopy 9.2, present during the 1992 survey was not observed during the current inventory.

Macrocystis canopy/planimeter areas increased significantly over that observed in 1992 (31%/25%), although canopy density remained statistically unchanged. Canopies 10.2, 10.5, 11.3, 12.1, 14.1, and 15.1 showed increases of over 50% in canopy area, and canopy 15.2 decreased by approximately 44% in surface extent.

B) Open Coast (Cape Flattery to Destruction Island)

Along the open coast, the total kelp canopy/planimeter area significantly decreased 40% and 24%, respectively.

Nereocystis canopy/planimeter area significantly decreased (85%/61%) when compared with similar areal extent data from 1992, and canopy density significantly decreased from .23 to .09. The canopies most affected by this decrease were located close to shore and relatively small in size within the range between Cape Flattery and Cape Alava.

Macrocystis canopy area also significantly decreased (22%) within the open coast range, although the planimeter area and canopy density remained statistically unchanged. As with *Nereocystis*, small *Macrocystis* canopies located close to shore between Cape Flattery and Cape Alava experienced the greatest reductions in areal extent.

C) Total Kelp Resource Range-wide (Port Townsend to the Columbia River)

The total kelp resource canopy area/planimeter area remained statistically unchanged since the 1992 survey (-5%/0%) , although canopy density was significantly reduced from .31 to .29.

This consistent resource extent was actually composed of a significant reduction in *Nereocystis* canopy/planimeter areal extent (28%/16%), and a significant increase in *Macrocystis* planimeter areal extent (18%). *Nereocystis* canopy densities were significantly reduced, while *Macrocystis* densities remained statistically un-changed.

D) Port Townsend to Disque (1.1-9.3) and Twin Rivers to Cape Flattery (10.1-16.2)

The total kelp abundance remained statistically unchanged from Port Townsend to Disque. However, kelp canopy/planimeter area increased significantly (14/20%) from Twin Rivers to Cape Flattery, due to significant increases in *Macrocystis* canopy/planimeter area (31%/25%) within the range.

E) The Olympic Coast National Marine Sanctuary (Neah Bay to Copalis)

Within the Olympic Coast NMS, the total kelp canopy area significantly decreased (27%), while the planimeter area remained essentially unchanged (-10%). The overall canopy density significantly decreased from .36 to .29. The main component of the decrease was that of *Nereocystis* canopy/planimeter area, which experienced a significant reduction of 48% and 29%, respectively.

Macrocystis canopy/planimeter area remained statistically unchanged, while suffering a significant loss of canopy density within the range.

F) Neah Bay to Cape Alava in comparison with the remainder of the survey range

Within the range of Neah Bay to Cape Alava, a significant decrease in total canopy area occurred (28%), while the planimeter area remained statistically unchanged (-11%). The overall canopy density significantly decreased from .38 to .31.

The greatest component of the significant decrease was that of *Nereocystis* canopy area (48%). *Macrocystis* canopy/planimeter areas remained statistically unchanged (-15%/9%) , despite experiencing a significant reduction in canopy density.

Outside of this range, *Nereocystis* canopy area also significantly decreased (17%), while the planimeter area remained statistically unchanged (-10%). *Macrocystis* canopy/planimeter area significantly increased (30%/23%), mainly due to increases within the Straits of Juan de Fuca. Canopy densities of *Nereocystis* significantly decreased when compared with the 1992 survey. *Macrocystis* canopy density, in addition to total canopy density within this range, remained statistically unchanged.

Kelp Canopy Species Composition (1992-1994)

Kelp canopy range-wide species composition in 1992, corresponding to canopy area values, was 49% *Nereocystis*/51% *Macrocystis* in mixed canopy areas, and 44%/56%, respectively, considering the total resource. In regards to planimeter area indices, these 1992 values were 50%/50% in mixed areas, and 55%/45% in reference to the total resource.

Canopy area species composition values for the 1994 resource, as previously summarized, were 21%/79% *(Nereocystis/Macrocystis)* within mixed canopies, and 34%/66% with regard to the total resource. In reference to planimeter area, canopy composition within mixed canopy areas was 37%/63% *(Nereocystis/Macrocystis)*, and 57%/43% within the range-wide surface canopy.

These changes in kelp canopy species composition between the 1992 and 1994 surveys further support observed range-wide significant decreases in the areal extent and density of the *Nereocystis* canopy, while the *Macrocystis* canopies increased significantly in planimeter area at statistically unchanged densities.

The principle findings from this 1994 kelp resource inventory are as follows:

1) The total Washington state coastal kelp resource within the survey range occupied a canopy/planimeter area of 825/2,850 ha, respectively, representing a statistically unchanged areal extent (-5%/0%, canopy/planimeter area values) from that observed during the previous (1992) inventory. Surface canopy densities for both species significantly decreased slightly throughout the range.

2) *Macrocystis* canopy/planimeter areal extent measured 548/1,537 ha, representing a consistent canopy area (12% increase), and a significant increase of 18% in planimeter area from that observed in 1992. *Macrocystis* canopy/planimeter area cover showed a significant increase (31%25%) within the Straits of Juan de Fuca, and a significant decrease in canopy area of 22% in the "open coast" portion of the range. Range-wide *Macrocystis* canopy densities remained unchanged.

3) *Nereocystis* canopy/planimeter areal extent measured 277/1,313 ha, representing significant range-wide decreases of 28%/16% over that observed in 1992. Decreases in *Nereocystis* canopy areal extent were greatest along the open coast (85%), and, to a lesser extent, within the straits of Juan de Fuca (15%). Range-wide *Nereocystis* canopy densities decreased significantly.

4) The survey sub-range/species showing the biggest decrease in resource areal extent was the "open coast", from Cape Flattery to Destruction Island. *Macrocystis* canopy area within this range was significantly reduced (22%) when compared with the 1992 inventory, while the planimeter area remained statistically unchanged (4% increase). *Nereocystis* canopy/planimeter areas were also significantly reduced (85%/61%). Sea surface "foam" obscured much of the small inshore kelp resource within this range, and amplified the already significant decreases in *Nereocystis* extent. Apparent significant decreases in *Macrocystis*, within this range, may have been caused by this foam obscuration.

5) The survey sub-range/species experiencing the greatest increase in kelp resource areal extent was that within the Straits of Juan de Fuca. Significant increases in *Macrocystis* canopy/planimeter areal extent (31%/25%) occurred within this range, while *Nereocystis* canopy area/density significantly decreased by 15%.

6) Canopy species composition shifted from an approximate 45%/55% balance *(Nereocystis/Macrocystis)* in both mixed canopy and total resource canopy area extent in 1992, to 30%/70%, respectively, in 1994. Planimeter area values changed from approximately 50%/50% (*Nereocystis/Macrocystis)* in mixed canopies and 55%/45% for the total resource in 1992, to approximately 30%/70% in mixed canopies, and 45%/55% with regard to the total kelp resource in 1994.

Discussion

This scope of this inventory was defined to provide a current, accurate measurement of the Washington state coastal kelp resource to promote a better understanding of the seasonal dynamics of this important habitat. In this regard, discussion will be limited to comparative methodology and the sources of error that may affect the accuracy of this current inventory, and its subsequent utility for multi-year comparative purposes.

The data acquisition and analysis methodology utilized in this survey was established for the 1989 inventory, and has remained consistent in all subsequent survey efforts. The only change in data acquisition parameters has involved reducing the survey altitude from 9,500' MSL in 1989 to 7,500' MSL in subsequent years, which improved resource rendition on the imagery. With limited exceptions, imagery from all surveys has been obtained within the "optimum survey windows", as previously introduced.

Accurate kelp canopy rendition, analysis, and validity of the major findings in this 1994 study were made possible by the good-excellent conditions under which imagery was obtained. Most flight parameters establishing an "optimum survey window" were present during the aerial image acquisition, and with limited exceptions, allowed accurate comparisons with the resource extent as depicted in the 1992 inventory.

Within the Straits of Juan de Fuca, the imagery was of excellent quality and allowed the complete rendition and analysis of the kelp resource. However, along the open coast, persistent sea "foam" from a previous storm was present, especially in "exposed" inshore areas. In addition, the open coast sea state was estimated at 6-8 feet, slightly higher than the "less than 5 foot" target. This combination of environmental parameters under which the imagery was obtained would have the effect of reducing the areal extent of kelp recorded on the imagery. Small groups of plants, located close to shore in exposed areas, would be most affected by these conditions, and might be completely obscured by the surface foam or pulled under by currents. *Nereocystis* plants, along the open coast, exhibit this growth pattern, and were probably significantly under-represented on the imagery. The accurate rendition of *Macrocystis* plants was also undoubtedly affected, but probably to a lesser degree due to its predominate growth in protected areas free of foam and wave action. As a result, when comparing the two surveys within this range, observed large decreases in *Nereocystis* canopy/planimeter area are likely exaggerated by these factors. This source of error in the analysis, while affecting the <u>magnitude</u> of observed changes from 1992 to 1994 within this survey range, <u>did not affect the statistical significance</u> of these and other major findings in this study.

Conclusion

The goals of this resource inventory were again achieved in the continuation of the systematic, state-wide measurement and analysis of the Washington coastal kelp resource. This survey provided important data regarding the status of current kelp canopy abundance, by species, in addition to comparisons with the 1992 inventory. These data were tabulated at several levels to aid individual research investigators, agency resource managers, and GIS professionals in an effort to better understand the factors that influence the seasonal dynamics, and related species diversity, of this magnificent near-shore habitat.

Glossary

Kelp Bed Canopy - An aggregation of surface kelp plants in close proximity to each other which produced a consistent infrared return on the imagery, such that individual plants were indistinguishable when projected at mapping scale (1:12,000)

Kelp Bed Index Numbers - Reference labels assigned to each distinct kelp bed, by map page. The total kelp resource on each map where kelp was present (W-1 to W-25) was divided into several discreet geographic areas, each with similar exposure to incoming seas and swells. These areas were numbered in the format: "Map Page. Kelp Bed Index Number" (ex. 10.3), with the number before the decimal corresponding to the map page that the canopy was found on, and the number after the decimal referencing the discreet geographic area on that page that the canopy occupied.

A few simple conventions were followed in establishing this indexing system: 1) break points between canopy numbers were referenced by fixed shoreline points wherever possible (see kelp bed # 8.1), 2) discreet "offshore" canopies were separated from "onshore" canopies (see kelp bed # 8.4), and, 3) map boundaries formed break points between kelp beds only if the bed was not bisected by the boundary. In that case, a single kelp bed index number was maintained between the pages, and was numbered with the map page where the greatest component of the kelp canopy was found (see 7.3). The extent of the qualitative canopy area (see definition) itself also formed natural "breaks" between kelp beds (see map W-10). Frequently, these natural breaks are due to lack of suitable sub-tidal habitat or invertebrate overgrazing. Kelp beds separated by these natural breaks that were similar in exposure, species composition and density, were grouped together by a common index number. Kelp beds with substantially different values for these indices were given discreet index numbers. This indexing system was established for the 1990 survey and has remained constant in subsequent replicate kelp canopy mapping efforts.

Kelp Bed Qualitative Canopy Area - The geographic (spatial) extent of individual surface kelp plants and canopies, as fully rendered from the original imagery. Each visible individual kelp plant and canopy was hand transferred to the "canopy area" maps, and represented by black-shading wherever present. Areas within the perimeter of the canopy that did not contain kelp were left un-shaded. This index depicted the actual appearance of the surface kelp canopy, as viewed on the original imagery.

Kelp Bed Quantitative Canopy Area - The numeric extent (hectares) of individual surface kelp plants and canopies. Each qualitative canopy area map was scanned into the image processing system at full scale (1:12,000), and subsequent screen "pixel counts" conducted. All "black-shaded" pixels that represented actual kelp at the surface were counted, individual pixel area determined, and a quantitative kelp canopy area established. This index represented numerically the actual extent of the surface kelp canopy, as mapped from the original imagery.

Kelp Bed Qualitative Planimeter Area - The geographic (spatial) extent of the surface kelp canopy contained within its own perimeter, assuming continuous kelp coverage within. Since the surface kelp resource was composed of individual plants and established canopies; this measurement systematically defined the perimeter and subsequent enclosed area of this plant assemblage, by species class. This value depicted kelp canopy areal extent in slightly different terms than "canopy area", as previously defined, and served three purposes in this analysis: 1) it allowed comparisons of current and historic estimates of kelp resource abundance, which utilized similar "perimeter" estimation methods, 2) it allowed an understanding of the sea surface area that was actually occupied or influenced by the kelp canopy, and 3) it allowed a measurement of kelp canopy density (see "relative density index").

Qualitative planimeter area, by kelp bed number and species, was established by computer enhancement of each scanned "canopy area" map. This methodology systematically established perimeter polygons around each "species class", and included all kelp plants inside the polygons that were within 50 meters of each other, giving each plant a 25 meter "radius of association" (2 mm at the 1:12,000 mapping scale). Within the analysis software ("Global Lab Image"-V3.1-Data Translation), individual kelp plants and canopies within each species class were "dilated" (expanded) with a "5x5" pixel "structuring element", thereby adding a 25 meter radius of kelp to each existing kelp pixel. Individual kelp plants within 50 meters of each other became part of the same perimeter, while plants greater than 50 meters apart retained discrete perimeters. Within established canopies, this transform had the effect of defining the canopy perimeter 25 meters beyond that visually apparent on the "canopy area" maps, as well as filling in the all of the "holes" in kelp coverage within the canopy. This computer synthesized value is spatially similar to that obtained by using a hand planimeter to determine kelp canopy areal extent, and hence the name. Many environmental surveys have used planimeter areas to describe resource abundance, since prior to computers, this was all that was available. In addition, by the nature of the process, area statistics from other hand digitized kelp resource maps (for data entry into a geographic information system, see definition), will closely approximate the quantitative planimeter area (see definition), thereby allowing comparisons. This index is always larger than the kelp "canopy area", which is a depiction and measurement of the sea surface area actually occupied by visible kelp plants. These computer established perimeters were transferred to the kelp "canopy area" maps, by species class, and presented as Section 5 - Kelp Bed Species Composition/Planimeter Area Maps: 1-25.

In addition to allowing comparisons with both historic (planimeter derived), and computer (digitizer derived) data, planimeter area measurements more accurately depict the influence, or sea surface area occupied, by kelp canopy species that have more irregular distributions (dense canopies in some areas and sparse areas containing individual plants in others). *Nereocystis* canopies are frequently observed with this growth pattern, and their prominence underrepresented by a strict "canopy area" analysis only.

Kelp Bed Quantitative Planimeter Area - The numeric extent (hectares) of the qualitative planimeter area. Each quantitative planimeter area, by canopy number and species was scanned into the image processing program, and a screen "pixel count" conducted. All pixels within the individual perimeters were counted, individual pixel area determined, and a quantitative canopy planimeter area established.

Kelp Bed Relative Density Index (RDI) - The percentage of the planimeter area that actually contained surface kelp plants. This index was calculated by dividing the canopy area by the planimeter area and approximated the probability of encountering kelp at a random point within the canopy perimeter. This value approaches "1" for very dense canopies and "0" for very sparse canopies. The measurement is independent of canopy size, and a good indicator of changes in density over time. In considering the relationship between canopy area and planimeter area, several examples underscore this basic relationship, and subsequent multi-year trends.

Canopy Area (ha)	Planimeter Area (ha)	Density (RDI)	Interpretation
10	20	.5	10 ha of kelp are contained within 20 ha of the sea surface that it occupies (prob. of encountering kelp within perimeter = .5)
5	20	.25	5 ha of kelp are contained within 20 ha of the sea surface that it occupies (prob. of encountering kelp within perimeter = .25)
Can. Chg.	**Plan. Chg.**	**Den. Ch**	**Interpretation - Multi-Year Trends**
10 to 10	20 to 20	.5 to .5	Kelp resource area (canopy area), spatial extent (plan. area), and density (RDI) **stable** over time
10 to 15	20 to 20	.5 to .75	**Increased** resource area within **similar** spatial extent at **inc. dens.**
10 to 20	20 to 40	.5 to .5	**Inc.** resource area and spatial extent at **similar** densities
10 to 20	20 to 30	.5 to .66	**Inc.** resource area and spatial extent at **increasing** densities
10 to 15	20 to 40	.5 to .38	**Inc.** resource area and spatial extent at **decreasing** densities
10 to 5	20 to 20	.5 to .25	**Dec.** resource area within **similar** spatial extent at **dec. density**
10 to 5	20 to 10	.5 to .5	**Dec.** resource area and spatial extent at **similar** densities
10 to 5	20 to 15	.5 to .33	**Dec.** resource area and spatial extent at **decreasing** densities
10 to 5	20 to 30	.5 to .38	**Dec.** resource area within **inc.** spatial extent at **dec.** densities

ERDAS (Earth Resource Data Analysis System) - A "raster" based image processing and geographic information system (see below)

- **Class Value** - A group of screen "picture cells" (pixels) or points within a closed polygon that share a common condition or attribute. In this study, three species class values were established: 100% Nereocystis , 100% Macrocystis , and mixed canopies.

- **Geographic Information System (GIS)** - A computer software platform designed to facilitate the assembly and analysis of diverse data sets pertaining to specific geographic areas using spatial locations of the data as the basis for the information system

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